

West Virginia University Libraries



3 0802 100789865 4

Digitized by the Internet Archive
in 2010 with funding from
Lyrasis Members and Sloan Foundation

Ag-100 Library
West Virginia University

Studies on the Post-harvest Physiology and Handling of Strawberries

WEST VIRGINIA UNIVERSITY AGRICULTURAL EXPERIMENT STATION
BULLETIN 596T, JUNE 1970

THE AUTHOR

Morris Ingle is Associate Horticulturist in the West Virginia University Agricultural Experiment Station.

West Virginia University
Agricultural Experiment Station
College of Agriculture and Forestry
A. H. VonLandingham, Director
Morgantown

Studies on the Post-harvest Physiology and Handling of Strawberries

MORRIS INGLE

SEVERAL STUDIES (4, 5, 8) have shown strawberries, one of the most perishable fruit crops, have a considerably higher respiration rate than such fruits as citrus, apples and peaches. As the marketing of strawberries shifts from roadside and local markets to large retail outlets in urban areas, the time between harvesting and final sale increases. More data on the post-harvest physiology and behavior of strawberries is required in order to devise better methods for maintaining commodity quality and reducing losses in marketing channels. With the exception of studies in California (6, 7) relatively little work has been done on strawberry fruit physiology in the last twenty years, and it was felt that data were needed on varieties now produced in the eastern United States, including West Virginia. With the development of newer methods, fruit respiration can be measured more accurately and under more physiological conditions than was possible in most of the earlier studies.

Methods

Most of the samples of fruit were obtained from the University Farm at Morgantown. Fruits were obtained from plants grown by the matted method. Fruit from a commercial planting located 60 miles from the laboratory was used in some of the temperature management studies. Approximately two hours were required to transport this fruit to the laboratory.

After arrival at the laboratory, the fruit was carefully examined and sorted to remove misshapened and diseased fruits and to eliminate fruits of extreme sizes. When maturity, or stage development, was to be studied the fruits were usually graded into four categories, based on the proportion of the fruit surface colored red—0-25%, 26-50%, 51-75% and 76-100%. The last category represents commercial ripeness. Weighed samples of the fruit were placed in glass jars which were used as respiration chambers. These were supplied with air from flowboards similar to those originally described by Claypool and Kiefer (3), which provide a known constant rate of airflow. The flow rate depended on the method of carbon dioxide analysis, but was always great enough to maintain a carbon dioxide concentration of less than 0.5 per cent.

At the conclusion of respiration and management experiments, fruits were sorted and classified as marketable and non-marketable. To maintain uniformity between experiments, this operation was performed by one worker. Fruits which showed fungal growth, excessive softness, excessive darkening of bruised areas, shriveling, or loss of color from calyx were classified as unmarketable.

Respiration rates were determined daily as carbon dioxide production. The carbon dioxide concentration in the air stream leaving the respiration jar was determined either by gas-liquid partition chromatography (silica gel column and thermal conductivity detector) or by infrared analysis (LIRA-cell) and respiration rates were calculated as $\text{CO}_2 \text{ kg}^{-1} \text{ hr}^{-1}$.

Results

The relationship between temperature and the rate of strawberry fruit respiration is shown in Figure 1, which is typical for many experiments conducted over several years. At 2° and 7° C the rate is nearly constant for about ten days, perhaps showing a slight increase during the last three days of the experiment. Increasing the temperature from 7° to 12° C about doubled the respiration rate, which remained essentially constant for four days. After that time decay and breakdown began, there was a sharp rise in the respiration rate. Respiration measurements were continued until the eleventh day after harvest even though it was obvious that essentially all of the fruit had become unmarketable by the end of the sixth day. During the period of decay the respiration tended to increase, but was erratic. At 20° C the respiration rate was five times higher than at 2° C and increased rapidly. After five days of breakdown and infection by fungi were extensive and the respiration measurements were terminated. Other samples held for more than ten days at 20° C sometimes showed a decline in CO_2 production, coinciding with visual indications of breakdown.

The respiration of fruits apparently at the same stage of ripeness was not constant, but varies between samples picked at different times. Table 1 shows rate of CO_2 production for several samples. Obviously there is considerable variation between samples. It is quite likely that this variation is related to environmental conditions before and at harvest, but detailed data were not collected on this relationship. It also must be pointed out that the stage of development was estimated visually by arbitrary criteria, and different lots of fruit probably were very different physiologically. The respiration data clearly indicated these differences.

From these respiratory data it is possible to obtain the respiration quotient (Q) for strawberry carbon dioxide production. It must be

TABLE 1

Respiration Rates for Various Samples of Strawberries Harvested in 75% Red or Pink (Commercially Ripe). CO_2 Production on First Day after Harvest.

Harvest date	Temperature			
	3° C	7° C	12° C	20° C
	mg CO_2 /kg/hr.			
6/24	33.4	25.3	55.3	83.3
6/24	11.3	11.1	41.2	87.6
6/25	17.3	24.3	42.8	84.4
6/26	22.2	171.8
6/26	60.1	198.8
6/26	25.0	169.0

and that this is variable and changes with time after harvest. Referring to Figure 1, the Q_{10} appears to be three on the first day after harvest in the range 2-12° and nearly three over the range of 7-12° C. The ratio of rates at 20° C to those at 2° is 5.8 on the first day after harvest and rises to 9.2 on the third day. This change is ascribable to the rapid increase in the rate of CO_2 production at 20° C. The ratios between the rate at 12° and 2° changes less dramatically from 3.0 on the first and third days to 5.2 on the sixth day. Q_{10} values have been found to range from 2.0 to 4.0.

RELATIONSHIP BETWEEN STAGE OF DEVELOPMENT AND RATE OF RESPIRATION

Strawberries will continue to develop color after harvest (1, 9), and it has been suggested that the storage and shelf life of strawberries might be extended by harvesting them at an earlier stage of color development than is commonly done at present. The respiration of strawberries harvested at four stages of development, as determined by the proportion of the surface colored pink or red, was followed. Data from a few experiments are shown in Table 2.

In some experiments, such as the fruit harvested on 6/2/65, fruit with the least and most amount of surface color had lower respiration rates than fruit with intermediate amounts of color. This was not always the case, however, as is shown for two other harvests (6/4/65) and 5/29/64). From Figure 2 it appears that the rate of respiration increases as the fruit becomes redder up to the stage of commercial "ripeness," after which the rate decreases. The less colored fruit (Classes 1-3) showed a consistently consistent increase in respiration over a six-day period at 12° C. The

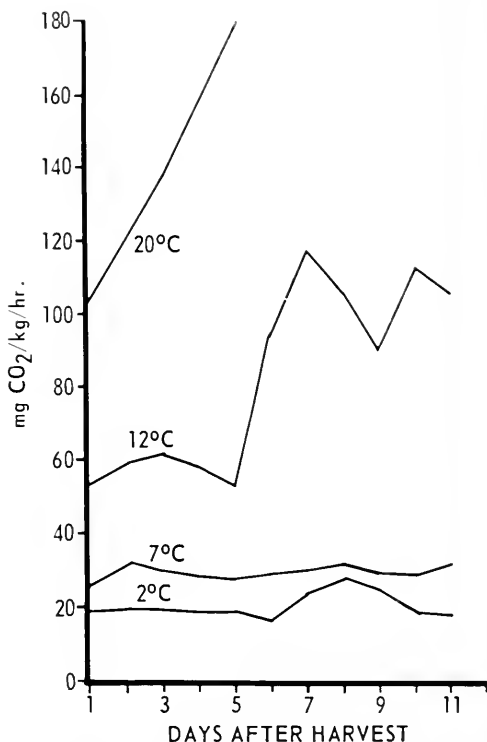


FIGURE 1. Respiration rate of ripe (color 4) strawberries at different temperatures.

rates of classes 1-3 were very similar during the last four days. The respiration of riper fruit (Class 4), however, increased for some five days and then declined. Fruits harvested when incompletely colored were firm and sound after eight days at 12°C, while the fruit which was harvested when commercially ripe had become deep red in color, dull finish, very soft, and showed fungal contamination and breakdown.

Although fruits harvested with 50-75 per cent red color have a slightly higher rate of respiration than more highly colored fruits, it appears that they can be kept in storage for a longer period of time.

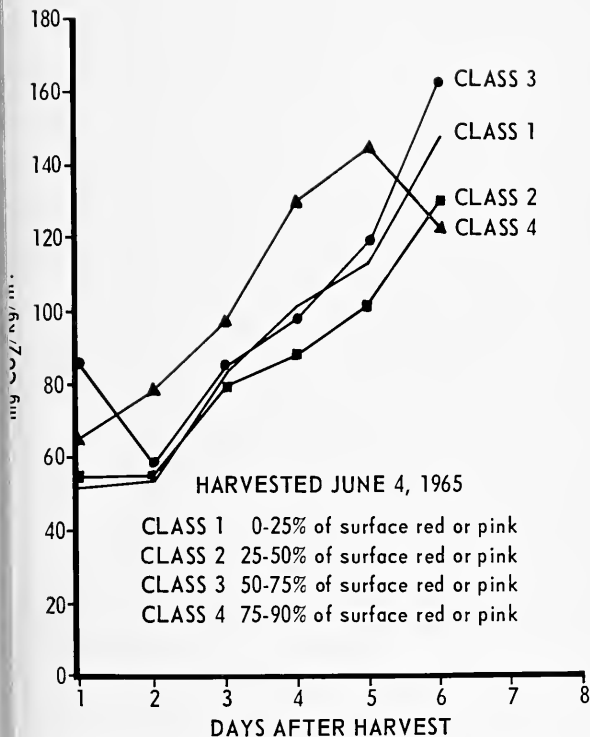


FIGURE 2. Rate of respiration of strawberry fruits after harvest at four stages of development.

TABLE 2
Carbon Dioxide Production 24 Hours after Harvest at 12°.

Harvest date	Maturity ¹			
	1	2	3	4
	mg CO ₂ /kg/hr.			
1934	71.3	55.9	45.9	83.3
1935	27.8	62.5	54.3	42.4
1935	52.5	55.8	56.7	78.3

¹Class 1, 0-25% red; Class 2, 26-50% red; Class 3, 51-75% red; Class 4, 76-100% red.

determine if the quality of fruit which colored after harvest was different from fruit harvested at the customary stage of development. Soluble solids and pH of juice were determined (Table 3 and 3A). In one experiment, fruits in Classes 2, 3, and 4 were harvested on the same date and held for eight days at 2° C. At the end of that period, 90 per cent of the fruits were still sound and had sufficient color for marketing.

TABLE 3

Percentage Soluble Solids and pH of Fruits Harvested at Different Stages of Development. Data Taken after 8 Days Storage at 2° C.

Color class at harvest	pH	% Soluble solids
	<i>Midway</i>	
2	3.35	5.08
3	3.42	5.19
4	3.58	5.47
	<i>Surecrop</i>	
2	3.27	5.52
3	3.38	5.99
4	3.45	6.32

Soluble solids at harvest in fruit harvested ripe were 5.21% for Midway and 6.05% for Surecrop.

TABLE 3A

Percentage Soluble Solids of Fruits Harvested at Different Stages of Development.

Color class at harvest	Initial soluble solids	Soluble solids after storage at 22° until fully red	% Soluble solids after storage 22° until fully red
2	6.25	5.77	6.59
3	6.66	6.75	6.64
4	6.60	6.73	

In another experiment soluble solids were determined in three classes of fruit before and after storage until 100 per cent colored.

These data suggest that there are small differences in soluble solids and pH between fruits harvested at different stages of color development. At lower temperatures, earlier harvested fruits failed to develop levels of soluble solids equal to fruits fully colored when harvested but the differences were small. The soluble solid content of Class 3 and Class 4 fruits stayed constant or increased slightly when stored at room temperature (22° C) while the soluble solids of Class 2 fruits decreased under similar holding conditions.

TEMPERATURE MANAGEMENT

Studies by Maxie *et al.* have shown that the interval between harvest and the reduction in fruit temperature is critical in maintaining the quality of California strawberries. Since different varieties of strawberries are grown in California and the eastern United States, it seemed advisable to investigate this aspect of temperature management.

Fruit was collected as it was brought to the field assembly point by individual pickers; flats of fruit that had been harvested within the same time interval were obtained. After the fruit arrived at the laboratory, subsets of fruit from the trays were distributed into groups for treatment. This procedure was used to at least partially reduce picker variability. At certain intervals after harvests, lots of fruit were placed in a laboratory forced-air cooler which operated at a static head of 0.5" water and 4 F/lb of fruit. With an ambient temperature of 3° C, fruit temperature was reduced from 22° C to less than 6° C in two hours. After this time the fruit was stored at 2° C until evaluated or transferred to 20° C for simulated shelf life.

Table 4 shows data from one of several experiments performed in 1964 and 1965 with the Surecrop variety. The quality of the fruit, when evaluated after six days storage at 2° C and one day at 20° C was not affected by the interval from harvest to cooling. In these experiments the shelf life was only extended to nine hours because it was thought that in some cases the fruit could be delivered to a cooling facility within that time.

A subsequent experiment showed that in some cases the time from harvest to cooling may affect fruit quality. Table 5 shows that the quality of Surecrop berries evaluated after six days at 2° C was not affected by delay in cooling. This is in agreement with the experiment discussed previously; however, the Midway variety showed differences in quality related to the harvest-to-cooling interval, and those differences were even more pronounced after a simulated shelf trial of three days.

TABLE 4
Effect of Cooling Delay on Quality of Surecrop Strawberry Fruits.²

Interval from harvest to beginning of cooling	Per cent marketable by weight after	
	6 days at 2°	1 day at 20°
3 hours	89.2	92.3 ¹
5 hours	95.7	94.3
7 hours	92.8	95.5
9 hours	98.6	96.9

¹ Fruit unmarketable at first evaluation discarded.

² Fruit maintained at 20° continuously after harvest was unmarketable two days after harvest.

TABLE 5
Effect of Cooling Delay on Quality of Surecrop and Midway
Strawberries.

Interval from harvest to beginning of cooling (hrs.)	Per cent marketable by weight after	
	4 days at 2	3 days at
<i>Surecrop</i>		
1	91.3	82.0
3	93.9	78.8
4	91.7	81.9
5	92.8	90.9
6	95.3	89.8
<i>Midway</i>		
1	92.5	75.8
3	86.3	83.2
4	90.2	76.1
5	83.7	69.7
6	69.4	67.9

Fruit unmarketable at first evaluation discarded.

The data in Table 6 also suggest that early field heat removal is important in maintaining strawberry quality. In that test cooling was begun until 7-13 hours after harvest, and after 1 day at 3° C and 1-1½ days at 20° C, 70 per cent or less of the fruit could be classified as marketable. Earlier cooling times were not used in this test, but similar tests conducted a few days earlier with fruit from the same planting showed much higher percentage of marketable fruit.

It seemed important to determine how subjecting strawberry fruit to different temperatures would affect quality. For these studies experimental lots were assembled as described for the delayed cooling study. One lot was maintained continuously at room temperature (20° C); other lots were alternated between 3° C and 20° C. The total holding time was 72 hours.

An examination of the data in Table 6 suggests that successively exposing strawberry fruits to relatively low and high temperatures does not affect quality adversely; rather, the total hours at a given temperature is the principal factor controlling fruit quality after harvest. Treatment 4 in Table 6 was subjected to one more cooling and heating cycle than Treatment 3, but since the fruit in Treatment 4 was at 3° C longer than the fruit in Treatment 3, there was more marketable fruit in Treatment 4 at the end of the experimental holding period. Holding at 3° C for 50 per cent of the period at least doubled the percentage of marketable fruit compared with fruit held continuously at 20° C.

TABLE 6

Effect of Alternating Temperatures after Harvest on Strawberry Fruit Quality.

Time in hours		Time at 3° and 20° C ¹							Per cent marketable by weight	
		0	12	24	36	48	60	72	Midway	Surecrop
0	3°									
0	20°								42.3	25.2
	3°									
60	20°								86.0	85.8
	3°									
24	20°								63.9	67.4
	3°									
36	20°								84.0	83.7
	3°									

Bars indicate time interval fruit was held at 3° C or 20° C.

The influence of alternate warming and cooling was also studied by comparing the respiration of precooled with non-precooled fruits. Uniform samples were cooled 2-5 hours after harvest in a laboratory forced-air cooler and then distributed into respiration chambers. Comparable samples were held at room temperature and placed in respiration chambers at the same time as the precooled fruit. The first respiration rate measurements were made about eleven hours after harvest. Respiration data are tabulated in Table 7.

TABLE 7

Effect of Precooling on Respiration Rate of Strawberries. (Surecrop Variety)

Initial treatment	Holding temperature	Hours after harvest				
		6	24	48	72	96
Respiration rate - mgCO ₂ /kg/hr.						
Non-precooled	3°	38.3	8.9	17.6	14.8	13.1
Precooled	3°	23.2	12.9	17.1	16.4	19.4
Non-precooled	25°	104.8	55.6	123.1		
Precooled	25°	52.7	58.9	122.6		

The effect of precooling on respiration at the time of the first measurement (6 hours) is evident. The non-precooled fruit at 3 °C was cooling slowly and still had a higher respiration rate than the precooled fruit at the same temperature. On the other hand, the effect of precooling on respiration of fruit held at 25 °C was evident for several hours. Within 6 hours, however, the effect of precooling on respiration was dissipated, and at the time of the second measurement, the rates of the precooled and non-precooled fruit were essentially identical. When the samples held at 25 °C were examined three days after harvest, the precooled and non-precooled treatments contained approximately equal amounts of marketable fruit (precooled, 79.1 per cent vs. non-precooled, 76.5 per cent). These data would suggest that short-term temperature changes have no appreciable effect on fruit respiration or quality.

METHOD OF PRECOOLING

Based on the relationship between temperature and respiration rate, it would be anticipated that rapid reduction of fruit temperature should result in higher fruit quality. The two methods of precooling (rapid reduction of fruit temperature) that appear to be applicable to strawberries are forced-air cooling and hydrocooling. The possible effect on fruit quality is one of the factors that should be considered in the selection of a precooling method.

Twenty-four quarts of Surecrop strawberries were divided into three groups. One group was cooled to less than 5 °C in the laboratory forced-air cooler. This cooling required approximately two hours. The second group was cooled by showering with water chilled to 2 °C by a small constant temperature water bath equipped with mechanical refrigeration. Each quart of fruit was cooled individually. Twelve to fourteen minutes were required to reduce fruit temperature to less than 5 °C. Each quart was transferred to a refrigerated room as soon as cooling was complete. The third group was held continuously at 25 °C. After three days fruit were classified as marketable or unmarketable. All of the fruit was held an additional three days at 25 °C and again evaluated. The results of the evaluations are shown in Table 8.

The method of cooling had no effect on quality of fruit after the storage periods. There was no indication decay organisms were transferred between containers in the hydrocooler. It is likely that the quantity of fruit involved in this experiment was too small to have made dispersal of decay organisms a problem. It was noted that the fresh weight of hydrocooled berries had not changed after three days in storage while that of the forced-air cooled berries had decreased by 3.3 per cent of their original weight. Since there was no obvious differences in

TABLE 8

Effect of Cooling Method on Strawberry Fruit Quality.
(Surecrop Variety)

Treatment	Per cent marketable fruit Days after harvest	
	3	6
Forced-air cooled	94.5	65.3
Hydrocooled	94.2	67.5
Non-cooled	24.7	13.4

pearance of the two groups of fruit, this weight change difference did appear to be important.

Discussion

When a fruit such as the strawberry is harvested it is removed from source of water and organic compounds. As respiration continues, carbohydrates and perhaps other constituents will be degraded. Extensive tissue breakdown and breakdown of tissue components lead to changes in structure and appearance of the fruit. Respiration is not the only complex of processes which occurs in harvested fruits that result in quality changes, but it can be used as a convenient index of metabolism because respiration is relatively simple to measure.

Respiration, as defined by carbon dioxide production, is highly dependent on temperature. Temperature increments of 10°C have been found to raise the respiration rates of strawberries as much as fourfold. This would indicate that a primary objective of any management or handling system for strawberries must be protection from high temperatures. While this is true for any perishable commodity, it is particularly critical for strawberries because of their comparatively high rate of respiration. At low temperatures strawberries may have a relatively constant respiration rate for ten to twelve days, but at common outside early-summer temperatures—around 25°C —the respiratory rate rises rapidly after harvest (Figure 1). Since the rise is much less and develops more slowly at temperatures of 12°C or so, relatively simple temperature management systems would be expected to materially retard strawberry fruit deterioration. The work reported in these studies shows that over 60 per cent of fruit stored at 20°C became unmarketable after three days while at 2°C there were no significant changes in quality for ten days or even longer.

Because of the effect of temperature on fruit respiration and deterioration, it would seem logical to maintain low fruit temperatures whenever possible. Temperature alternations do not accelerate strawberry

fruit breakdown. Rather, data reported here and by Maxie *et al.* (6, 7) demonstrate that fruit quality is proportional to temperature; that is, the quantity of marketable fruit after a given holding period depends upon the time the fruit is held at a relatively low temperature.

Fruits are sometimes divided into two groups (2). Climacteric fruits show a definite rise in carbon dioxide production during the latter stage of development. This rise is usually associated with color changes, accumulation of certain compounds such as sugars, and perhaps softening. Other fruits, termed non-climacteric, generally show a decreasing rate of carbon dioxide production as they approach "ripeness" or the edible state usually characterized by being fully colored. Strawberries are considered to belong to the non-climacteric group. The data from these studies tend to confirm this concept. In some experiments samples containing fruit with intermediate coloring (maturity Classes 2 and 3) did show a higher rate of carbon dioxide production than samples with Class 1 and 4 fruit; however, this pattern was not consistent. The general pattern seems to be an increasing rate of CO₂ production with increasing maturity. Maturity Class 4 fruits at higher temperatures (20° C.) show a very rapid rise during the first 48-72 hours after harvest followed by a decline of around 50 per cent. At 12° C the rise is slower, lasting up to 120 hours. Less mature fruit show a rather gradual increase for 6-8 days with perhaps a slight decline after that time. Climacteric patterns may be difficult to demonstrate in massed samples where fruits are matched on the basis of visual characteristics. Several measurements with single fruits through the period of color development did not show a consistent peak of carbon dioxide production. Another characteristic of the climacteric rise in carbon dioxide production is an increased evolution of ethylene. In these studies many attempts were made to detect ethylene, but only trace amounts were ever found, and then only samples of over-ripe fruits showing fungal infection. The available evidence supports the conclusion that the strawberry is a non-climacteric fruit.

These studies would suggest that it is feasible to harvest strawberries at an earlier stage of development than is the present practice. Fruits of maturity Classes 3 and 4 do not differ greatly in soluble solids and pH, two characteristics that are important in determining fruit quality. Under unfavorable transportation and marketing conditions that would include prolonged holding at prevailing temperatures, harvesting when the fruit is 60-70 per cent colored may extend the total marketing opportunity from two to three days.

Maxie *et al.* in their work with California strawberries have emphasized the rapid decline in quality as the time between harvest and removal of field heat is extended. Their data indicate that normally fruit

ould be placed in precoolers within three hours after picking. The
profits of prompt cooling were apparent even when quality evaluations
were made as soon as 72 hours after harvest. The data reported in this
report would suggest that rapid handling is not so critical in West Vir-
ginia. There were no consistent differences in quality of Surecrop straw-
berries correlated with harvesting-to-cooling intervals of two to ten hours.
There is some evidence that the interval may be more critical with the
Honey variety, which appears to deteriorate more rapidly than Sure-
crop. The differences between the findings reported here and those from
California can be attributed in part to varietal differences. Also, the pre-
cooling temperatures in California may have been higher than they were
when this work was done in West Virginia. The present information
clearly indicates that early refrigeration is beneficial at least in maintain-
ing strawberry quality.

Holding strawberries alternately at low and high temperatures does
not affect quality adversely. Since the data from these studies and else-
where show that quality decreases in proportion to the time at high tem-
peratures, the use of refrigerated holding and transportation facilities
should be used wherever available.

Literature Cited

- Justin, M. E., V. G. Shutak and E. P. Christopher. 1960. Color changes in har-
vested strawberry fruits. *Proc. Amer. Soc. Hort. Sci.* 75:382-386.
- Male, J. 1960. Respiration of fruits—*Handbuch der Pflanzenphysiologie* 12(2):
16-92.
- Gaypool, L. L. and R. M. Kiefer. 1942. A colorimetric method for CO₂ determi-
nation in respiration studies. *Proc. Amer. Soc. Hort. Sci.* 40:177-186.
- Miller, M. H., P. L. Harding, J. M. Lutz, and D. H. Rose. 1931. The respiration
of some fruits in relation to temperature. *Proc. Amer. Soc. Hort. Sci.* 28:583-589.
- Miller, M. H., P. L. Harding and D. H. Rose. 1932. The interrelation of firmness,
weight, and respiration in strawberries. *Proc. Amer. Soc. Hort. Sci.* 29:330-
341.
- Maxie, E. C., F. G. Mitchell and A. Greathead. 1959. Quality study on straw-
berries. *Calif. Agr.* 13(1):6, 15.
- Maxie, E. C., F. G. Mitchell and A. Greathead. 1959. Studies on strawberry
quality. *Calif. Agr.* 13(2):11, 16.
- Gerholser, E. L., M. B. Hardy, H. D. Lochlin. 1931. Respiration studies of
strawberries. *Plant Physiol.* 6:549-557.
- Smith, W. L., Jr., and P. H. Heinze. 1958. Effect of color development on quality
of post-harvest ripened strawberries. *Proc. Amer. Soc. Hort. Sci.* 72:207-211.

